ELECTRICAL DISCHARGE COATING OF CERAMIC-METAL COMPOSITE ON METAL SUBSTRATE USING POWDER COMPACT ELECTRODES

A Thesis Submitted

In the Partial fulfillment of the requirement for the degree of

Master of Technology

in

Production Engineering

By

TIJO D

(Roll No.212ME2294)

Department of Mechanical Engineering

National Institute of Technology

Rourkela -769 008 (India)

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DEDICATED TO

MY LOVING PARENTS

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**Electrical Discharge Coating by ceramic-metal composite on metal substrate using Powder Compact Electrodes**" being submitted by Tijo D (212ME2294) for the partial fulfillment of the requirements of **Master of Technology degree** in **Production Engineering** is a bonafide thesis work done by him under my supervision during the academic year 2013-2014 in the Department of Mechanical Engineering, National Institute of Technology Rourkela, India.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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Tijo D

Abstract

EDM is a prominent non-traditional machining process, which is widely used for machining hard materials those are not possible by conventional processes. A very special aspect of this process is surface modification by material transfer from the tool electrode to the work-piece which is commonly known as an electro discharge coating (EDC). In this work, electrode prepared with tungsten (W)-copper (Cu) and with titanium carbide (TiC)-copper (Cu) powder by powder metallurgy (PM) route used as tool material and pure aluminum and AISI 1020 mild steel are used as work-piece. Using reverse polarity (tool as anode and work-piece as cathode) in electro discharge machine hard composite layer of WC-Cu on Aluminium substrate and TiC-Cu on AISI 1020 mild steel substrate have been deposited. The effect of compaction pressure during tool preparation by PM method and peak current (Ip) and pulse on time (Ton) during the EDC process on Deposition Rate (DR), Tool Wear Rate (TWR), Micro Hardness has been studied. Surface roughness of the coated surface have also been measured. Microstructures of the deposited layers are studied by using the optical images, while the compounds present in the coating are analyzed by XRD (X-Ray Diffraction) technique.

Keywords: Electro Discharge Machine (EDM), Surface Modification, Electro Discharge Coating (EDC), Powder metallurgy (PM) electrodes, Taguchi Analysis.

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Chapter 1

Introduction:

Electro Discharge Machining (EDM) is a prominent non-conventional machining process, where material is removed by generating sparks between two electrically conductive objects; the electrode and workpiece. EDM employs high frequency sparks for machining electrically conductive materials. The electrodes employed in EDM should have basic properties such as high electrical and thermal conductivity, low wear rate and resistance to deformation during machining. Even though EDM is generally used as a material removal process, efforts have been made to use it as a surface treatment or modification process. A very special aspect of surface modification by EDM where material is transferred from the tool electrode to the work-piece is commonly known as Electro Discharge Coating (EDC).

Electro discharge coating (EDC) is a non-conventional coating method developed in the recent years to form a hard layer on metallic work piece by using an electrical discharge in a dielectric medium. EDC can be used to improve properties like hardness, wear resistance, corrosion resistance of different engineering materials, without any significant change in the bulk workpiece material.

1.1 Various Surface Coating Techniques

The purpose of coating is enhancement of the substrate properties by improving its hardness, wear resistance and corrosion resistant property. At present there are number of coating techniques are available for surface alloying or surface modification. Some of the commonly used surface modification methods are described below.

1.1.1 Electroplating

Electroplating or electro-chemical plating is an electrolytic process where, anode is generally made of metal being plated so it serves as coating metal and work-piece in which coating to be done is known as cathode. Direct current from an external power source is passed through dielectric medium. But this method is limited to only certain materials and have limitations like it is time consuming and the adhesion of coating with substrate is not so good.

1.1.2 Plasma arc coating

It is a thermal spraying process that deposits a coating on the internal surface of a cylindrical surface or external surface of any geometry. In plasma spray devices, an arc is formed between two electrodes in a plasma forming gas, which usually consists of argon, hydrogen or helium. As the plasma gas is heated by the arc, it expands and is accelerated through a shaped nozzle. The particles flatten when they impinge on the surface of the substrate, due to their high kinetic energy. But the high temperatures associated with the plasma jet can result in carbide decomposition or excessive oxidation when spraying in air, giving carbide coatings with lower hardness or metallic coatings with higher oxide levels. Also the equipment used in the plasma arc coating is not suitable for manual operation and requires use of automated gun manipulators.

1.1.3 Physical Vapor Deposition (PVD)

Physical Vapor Deposition (PVD) used to deposit thin films by the condensation of a vaporized form of the required film material on to various workpiece surfaces. The coating method involves purely physical processes such as high-temperature vacuum evaporation with subsequent condensation. But PVD technologies typically operate at very high temperatures and required special vacuum apparatus. The rate of coating deposition is also very slow.

1.1.4 Chemical Vapor Deposition (CVD)

Chemical vapor deposition (CVD) is a chemical process used to produce high-purity, high-performance solid materials. CVD involves the flow of gases into a chamber containing one or more heated objects to be coated. As they pass over or come into contact with a heated substrate, they react or decompose and form a solid phase, which has been deposition of thin films onto the substrate. One of the primary limitations of this process is that sometimes the reactions are incomplete and the process is very slow.

1.1.5 Laser Coating

Laser coating, also referred as “laser cladding” or “laser spraying”, is an advanced coating technology for improving surface properties of the various components and equipment. In this method a second material is applied to the surface and melted by laser beam to alloy with a thin surface layer of the base material or to bond with the surface. As capital cost of laser is high and due to short interaction time the alloys that required long soaking times for heat treatment difficult to modify by this method.

1.1.6 Electro Discharge Coating (EDC)

EDC is a non-traditional coating technique in which hard layers can be obtained by using powder materials like Ti, W, Cr etc. This technique has some specific advantages over other coating process that made it as a key research area in the field of surface engineering. The EDC can be done by using various methods to create hard layers on the work piece surface. It is possible to create hard layers with better properties and integrity on the work piece surface by material transfer from the tool electrode. But it is important in this process to maintain the tool as anode and work piece as cathode (reverse polarity) for material removal from the tool and deposited on the workpiece surface.

1.2 Advantages of EDC

The method of EDC has many benefits over some conventional coating techniques. As already described, there are many techniques to enhance surface properties of materials i.e. electro plating, plasma arc coating, laser coating and chemical/physical vapor deposition (CVD/PVD). But many of these methods required high capital cost and expensive equipments. EDC techniques can be used as an alternative approach to produce hard and wear resistance coating in different engineering sector. The advantages of the EDC method over the conventional methods are summarized below:

1. It does not require complicated equipment like vacuum apparatus.
2. With the help of an ordinary EDM machine tool, hard layers of different material composition can be easily created on the workpiece surface.
3. Coating layers can be created in various parts of the work piece and the thickness of the coating can be well controlled.
4. There is a large range of material can be used in EDC method as per the requirement of what coating is required on the workpiece surface.
5. Since EDC method is simple, it has a wide range of application as compared to other conventional coating techniques.

1.3 Applications of EDC

EDC is widely used because of its simplicity, less cost of operation and easy set up. With the help of an ordinary EDM machine coating can be done. Some of the major applications of EDC are as follows:

1.3.1 Roll Texturing

Surface modification technique by the EDM is used in roll Texturing. Surface modification and combined electrical discharge texturing (EDT) of Sendzimir rolls, which is used for production of stainless steel strip. Roll Texturing results in an increase of hardness of work piece materials, improves roll life and its performance.

1.3.2 Die and mould industry

EDC can be used in various industrial applications like tool, die and mold manufacturing, so that wear, corrosion and oxidation resistance of tool, die and mould could improve. EDC can be used in lightweight alloys (used in automobile and aerospace industries) like Aluminum and its alloy to improve their wear resistance.

1.4 Different Mechanism of Electro Discharge Coating (EDC)

Surface modification by using EDM is performed by various research groups over decades now. Many surface changes were observed and reported after such a process was established. By selecting suitable process parameters, the surface modification can be done with desired functional behavior. Surface modification by using EDM can be done by different mechanisms. The various methods of EDC and their mechanism are summarized below.

1.4.1 EDC by Powder Metallurgy (P/M) Electrodes

Surface modification can be achieved by electrical discharge processing with a liquid dielectric by using non-sintered, semi sintered or sintered powder compacted tool electrodes with reverse polarity settings in EDM. The tools are prepared by powder compaction methods. The weak bonding between the powder particles helps to achieve the necessary operating characteristics. Hard carbides are created by the reaction of decomposed carbon particle (C) from the dielectric, under high temperature, with the worn electrode materials (M). The carbide formed (MC) is then gradually piled up on the work piece surface and a thick hard layer is formed over the work piece as shown in Fig.1.

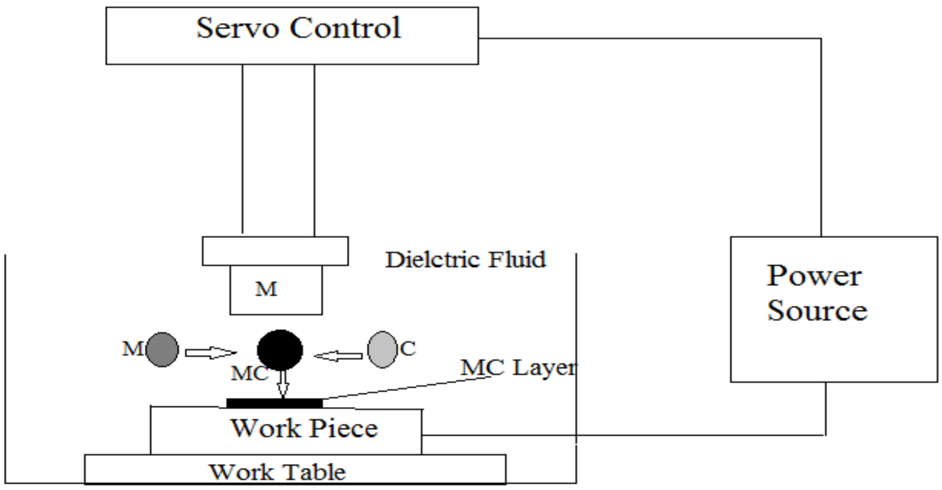

Fig.1: Principle of EDC by Powder Metallurgy method

Properties of powder compaction have an important role in this process, which is directly deposited or form particular type carbide on work piece surface. The properties of the coating are varied with the composition of powder and the type of powder using for making the electrodes. The P/M materials used for EDC include Ti, TiC, WC/Co, Ni/Co etc. The particle size of the powder ranges from 1 to 175 µm with compaction pressure approximately 100 to 540 MPa and sintering temperatures of 900 to 1300^{o}C.

1.4.2 EDC by Powder Suspension (P/S) Method

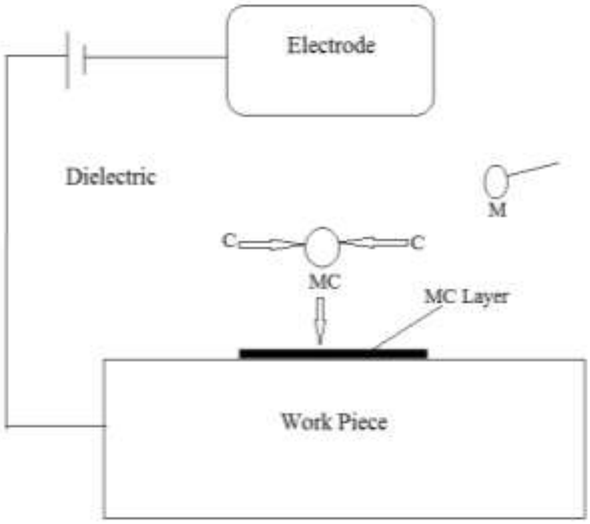

Fig. 2: Principle of EDC by Powder Suspension Method

EDC can also be obtained by powder suspended in working oil, so that the preparation of green compact electrodes can be eliminated. In this process, powder required for desired coating on the work piece surface is mixed into the dielectric. When a spark is generated between the electrode and workpiece surface, some reaction takes place between the suspended powder (M) and carbon (C), obtained due to decompose of dielectric and a layer of desired carbide form over the work piece surface as shown in Fig.2.

1.4.3 EDC by Conventional Electrodes

Surface modification by electro discharge can be done by using conventional solid electrodes also. By using solid metal electrodes as cathode and work piece as anode in the presence of hydrocarbon dielectric, a metallic carbide of workpiece material formed due to the reaction of the substrate with decomposed carbon from dielectric during the discharge process. In these conditions coatings with more resistance to wear and abrasion can be obtained. The solid metal electrodes used for this purpose includes Cu-W, Ti, Graphite etc.

1.5 Process Parameters of EDC

Parameters of EDC process is depends on the mechanism of the process. For EDC by P/M method, process parameters are mainly parameters during tool preparation and actual discharge process.

1.5.1 Electrode preparation parameters for P/M tool electrode

The parameters, uses in P/M tool preparation have significant influence in EDC. The appropriate values of these parameters have an influence on green compact electrode quality of the coating. The important parameters that influence P/M tool electrode preparation are given below:

a. Size of Powder Particles

The powder size ranges between approximately 1 to 175 µm. The size of powder particles has a significant influence on the quality of coating developed during EDC. If the size of particles is large the surface roughness of the developed coating will be more, hence coating may be improper and can be easily removed from the workpiece surface. The proper mixing of powder during tool preparation is also difficult if the powder size is larger than a certain limit. Again, particles with narrower particle size exhibited low sintering rate.

b. Powder Composition

For tool electrode preparation the powder composition is an important criteria, since it decides the properties of coating developed. The properties of the coating like mechanical, wear resistance, surface roughness, microhardness mainly depends on the composition of powder. Two or more powders can be mixed together during tool preparation, so it has significant influence on the tool wear rate and deposition rate.

c. Compaction Pressure

Compaction Pressure is a significant parameters, which have great influence on electrode preparation, since it influences the erosion of tool electrodes during the EDC process. Compaction pressure means the amount of force applying per unit area by the die over the powder particles in the press. The particle is loosely compacted, so that material is removed easily from the tool electrode during EDC and deposited over the workpiece surface. However, if the strength of compact increases more than a certain extent the tool wear may reduce so that the deposition rate also reduces. An optimum pressure should apply, so that tool gets sufficient strength as well material removed properly from the electrode during the discharge process.

d. Sintering Temperature

In cases of green powder compact bond between the powder particles is not strong enough to bind the particle together. So to enhance the strength of compact, sintering is done after compacting the powder. If the sintering temperature exceeds the melting point of metal powder, properties of metal powder changes. So sintering is done below its melting temperature. At a high sintering temperature the compacts become stronger. While electrodes sintered to full density may offer high conductivity and consistent sparking, but the release of material will be limited and as a result rate of surface alloying will be diminished. Therefore an optimum sintering temperature should be used, so that powder particles not melted during sintering, but a strong bond between the powder particles could be obtained. The sintering temperature of various material generally varies between 900 to 1300^0C.

1.5.2 EDM Parameters During Discharge

EDC process largely depends on the discharge take place between tool electrode and workpiece. There are some parameters affecting the EDC process during the EDM is operating. Each of these parameters have some significant influence on the coating obtained on the workpiece surface. The major parameters during discharge are given below.

a. Discharge voltage (V)

The preset voltage which determines the width of the spark between the tool electrode and workpiece is termed as discharge voltage. When a suitable voltage is applied across the electrode and workpiece, the electrode breaks down. Once the current starts to flow, voltage drops down and stabilizes the working gap level. Higher voltage increases the gap, which improves the flushing conditions. The deposition rate (DR), tool wear rate (TWR) and surface roughness increases with an increase in discharge voltage, since the electric field strength increases.

b. Pulse on time and Pulse off time (Ton and Toff)

The duration of the spark is referred as pulse on time (Ton). All the working process happens during pulse of time.With a longer pulse duration, more work piece material is melted away from tool electrode.

Time in between two sparks generated is known as pulse of time (Toff). Pulse off time is also referred as a spark off time or pulse interval. The pulse off time should be shorter for the faster tool wear, same time if Toff is too shorter the spark should not deionize and quench the spark.

c. Duty factor (Tau)

It is the ratio of pulse on time to total cycle time. Duty factor is important in respect of deciding the time of the spark and the time of spark terminates. High duty factor means the Ton is higher and spark will remain for a longer time and the process EDC. Duty factor is given by the following relation.

$$\text{Duty factor} = \frac{\text{Pulse on time (Ton)}}{\text{Total cycle time (Ton+Toff)}} \times 100 \qquad [1]$$

d. Dielectric medium

A liquid medium that fills the gap between the electrode and workpiece and acts as an insulator until a specific gap and voltage are achieved. The dielectric liquid should have basic properties like high dielectric strength, effective cooling and flushing ability. The spark is conducted through the dielectric and most dielectric fluids are hydrocarbon and some time deinonized water.The dielectric fluid flushed between the gap of tool electrode and workpiece to remove material during EDM.

e. Flushing pressure

The pressure at which the dielectric is supplied between workpiece and tool is refered as flushing pressure. Flushing is one of the important factors in EDM. The pressurized of fluid help in spark production and in removal of the debris and also helpful for cooling the electrode and workpiece. Therefore, in EDC dielectric generally used without flushing.

Chapter 2

Literature Review:

After the development of the EDC process many research work was done in the field of on Electro Discharge Coating. This chapter includes some of the research work related to EDC in order understand the EDC technique and the types of EDC available and possibility of new work in this field.

Gangadhar et.al (1990) performed surface modification of steel surfaces by using P/M compacted tool having 90% copper and 10% tin. The processing time they used was 3 min and the pulse currents and frequencies were 2.3, 5.3, 9.0, 13.0 and 18.0 A and 5, 10, 20, 40 and 80 kHz respectively. They found that, during electro discharge processing in a liquid dielectric medium with negative polarity and powder compacted electrodes, the metal transfer from the tool electrode to the work surface can be enhanced. Metallurgical, physical and chemical nature of the surface was altered by a suitable change in the ingredients and the compositions of the powder compact.

Samuel and Philip (1996) have done a comparison between coating by using conventional electrodes and by using P/M electrodes in EDM. Electrolytic copper powder has been used as the electrode material at a sintering temperature of 850 ^{0} C and compacting pressure of 500MPa. Their study establishes that P/M electrodes are technologically feasible in EDM**.** P/M electrodes are found to be more sensitive to pulse current and pulse duration than conventional solid electrodes.

Shunmugan and Philip (1999) used tungsten carbide powder compact electrodes containing 40% WC and 60% Fe. They achieved 25% to 60% improvement in abrasive wear resistance and 20% to 50% reductions in cutting forces with WC-coated HSS tools during machining. Even at extreme pressure and temperature conditions during metal cutting, WC-coated HSS tools have exhibited improved wear resistance.

Aspinwall et. al (2001) had used PM electrodes, to initiate surface modification by using EDM. Experimental work details the effects of EDM parameters on the hardness and composition of the white layer following die sink machining of AlSl HI3 tool steel and roll texturing of 2% Cr steel using partially sintered P/M electrodes made of WC/Co. Die sinking using WC/Co electrodes increased the surface hardness due to the presence of W, C and Co.

Simao et.al (2002) performed detailed experimental research on the surface modification/alloying and combined electrical discharge texturing (EDT) of Sendzimir rolls, used for the production of stainless steel strip. They have used powder metallurgy (P/M) green compact and sintered electrodes of TiC/WC/Co. they observed that, as the compacting pressure and sintering temperature for P/M tool preparation increased, the physical, electrical, microstructural, thermal and mechanical properties of the electrode change leading to higher Texturing performance.

Wang et.al (2002) studied surface modification of carbon steel by using EDM with the help of Ti or other compressed electrodes**.** The machining conditions they have used were discharge current of 2.2 to 10 A, pulse duration of 2 to 12 µs and duty factor of 5.88 %. From the experimental results they found that, surface of the layer is rich in Ti and the formed layer consists of 51 % TiC, 48 % Fe and remaining impurities.

Lee et. al (2003), used WC compact electrodes prepared under compaction pressure of 100 to 540 MPa and a sintering temperature of 1000°C. EDC was done with a current of 8 to 12A and open circuit voltage of 240 to 245 V. They found that the use of partially sintered powder metallurgy (P/M) electrode can encourage surface modification because the binding energy between grains is reduced as compared to fully dense products.

Moro et. al (2003), studied the surface modification system with EDM in the practical usage. They were prepared semi sintered TiC electrode at forming pressure of 98.1 MPa and temperature of 900 ^{0}C respectively. The EDM process parameters were discharge current of 8 A, pulse duration of 128 µs, duty factor of 5.9 % and time of the experiment is 16 minutes. They found that tool made of TiC electrodes extends its tool life in the cutting condition.

Simao et.al (2003) had conducted experiments by using a L8 Taguchi design**.** They made the P/M tool electrode by using WC/Co powder. EDC was done at process parameters, peak current 1 to 3 A, pulse on time and pulse off time of 20 µs and an open circuit voltage of 125 to 270 V. The use of partially sintered electrodes made from WC/Co resulted in the formation of a uniform modified surface layer with relatively few micro cracks, an average thickness of 30 µm and a surface hardness of 1319 HV.

Ho et.al (2007) had done surface modification of Ti–6Al–4V, using both conventional solid electrodes and powder compacted copper electrodes with a water-based dielectric fluid.

The tool electrode comprised of copper pellets soldered on copper rods. An experiment was conducted at open circuit voltage of 270V with peak currents of 0.1 to 2.9A in steps of 0.1 A. From the study, they concluded that the P/M electrodes produces greater alloying than the solid electrodes and PM electrodes used with positive polarity produces thicker recast layers.

Patowari et.al (2010) used artificial neural network model in surface modification by EDM using tungsten (75%) and copper (25%) powder metallurgy sintered electrodes. The P/M electrodes were made at a compaction pressure of 120 to 300 MPa and sintering temperature of 700 to 900^0C. Two output measures, material transfer rate and average layer thickness, was correlated with sintering temperatures for EDC process. EDC was done at a voltage of 40 to 45 V, peak current of 4 to 12A and pulse duration of 19 to 386 µs.

Furutani et. al (1998) studied surface modification methods by using powder mixed dielectric. Ti powder was suspended in kerosene like dielectric. The EDC process was done at a peak current of 4 to 12 A, voltage of 80 to 320V and pulse on time and pulse off time of 2 to 2046 µs. The powder was adhered on a work piece after reacting with carbon. They made a wide area with uniform thickness, which was deposited with gear shape rotating electrode. Different powders, like Ti and Ni mix was suspended in water and hence TiNi layer was also fabricated.

Wu et.al (2005), had studied the EDC process by addition of Al powder in dielectric medium. A fine surface roughness value of the work piece is obtained from their experimental result. An optimal surface roughness (Ra) value of 0.172 µm was achieved under the process parameters of discharge current 0.3A, pulse duration time 1.5 µs, open circuit potential 140 V and gap voltage of 90 V.

Yan et.al (2005), studied the effect of urea added dielectric by modifying the surface of titanium in EDM. The used copper electrode and experiments were performed with peak current of 0.5 to 12A, pulse duration of 25 to 300 µs, open circuit voltage of 240 V and duty factor of 50 %. The experiment was done for time duration of 5 minutes. From the experimental results they found that under suitable experimental conditions, the modified surface of Ti metal exhibited improved friction and wear resistance. By adding urea to dielectric the surface roughness was also reduced with increase of peak current.

Kumar and Batra (2010) had done surface modification of die steel materials by EDC method using tungsten powder mixed dielectric. The various machining parameters were sparking voltage 135V, peak current 2, 4, 6 A, pulse on-time 5, 10, 20 µs and pulse off-time

38, 57, 85 µs. They observed that under appropriate condition, a significant amount of material transfer can take place from the powder suspended in the dielectric medium to the work material. From a negligible percentage of tungsten in the base material, it was possible to achieve a maximum of 3.25% tungsten in the surface of H13 die steel.

Pichai and Apiwat (2012) had done the surface modification of tungsten carbide by using titanium powder suspended in dielectric fluid. The EDM parameters considered were peak current of 10, 15, 20, 25A, open circuit voltage of 150V, sparking time of 15, 30, 60 minutes and duty factor of 50%. They obtained a surface coating composed of titanium and carbon. The coating surface contains less cracks and its surface hardness, increased from 990 HV to 1750 HV, which is close to the hardness of titanium carbide.

Hwang et.al (2010) describes the deposition of TiC coating layer on the surface of Nickel by EDC using multilayer electrode. The machining conditions they considered were open circuit voltage of 90V, pulse on time of 20, 80 and 150 µs and discharge current of 8, 12 and 20 A. They found that, carbon element with high concentration could increase the combination of Ti and carbon (C) to become TiC, enhance the surface hardness of the coated layer, decrease surface roughness of the coated layer and reduces the formation of micro cracks.

2.1 Problem Identification and Objectives

From the literature, it is found that most of the research papers explained the mechanism of the EDC process by Powder Metallurgy (P/M) method and powder suspension methods. It is found that, very less research work was done so far on the surface modification of Aluminium and its alloy by applying EDC process. Also, no specific work was done on TiC coating on the mild steel substrate due to difficulty in preparation of TiC tool compact. So, surface modification of Al and mild steel could be carried out by the P/M method with different tool electrodes. Again, very little work was found on the effect of powder composition and compaction pressure during tool preparation by P/M methods and EDM parameters on deposition rate or deposited coating microstructure.

Al and Al alloys due to its light weight and high specific strength has recently attracted considerable attention in automotive and aerospace industry as a substitution material for steel, but its applications limited for low wear resistance. In order to improve wear resistance of Al, surface coatings can be a promising approach. Tungsten (W) and Tungsten carbide

(WC) materials are extensively used as a material for surface modification due to its high hardness, wear resistance and strength, ideal for tools, dies, machine parts, wear resistance equipment.

Mild steel is the most common type of steel providing material properties applicable for many applications. But mild steel has a relatively less hardness. The other weaknesses of steel are its corrosion and wear behaviour. Due to these drawbacks, surface modification methods are adopted to improve its strength, hardness, corrosion and wear resistances. TiC is used for surface modification of steel due its excellent wear resistance and thermal stability.

The objectives of the present works are as follows:

1. To develop a hard coating layer of WC-Cu on Al work piece surface and a hard coating layer of TiC-Cu on AISI 1020 mild steel.
2. To study the effect of various parameters like tool compaction pressure (TP), peak current (Ip), pulse on time (Ton) on deposition rate (DR), tool wear rate (TWR) and micro-hardness.
3. To study the microstructure of the coating by using the images obtained through an optical microscope.
4. To analyze the compounds present in the coating by using XRD (X-Ray Diffraction) technique.
5. To measure the micro hardness of coating using a Vickers micro hardness tester.

Chapter 3

Experimental planning and procedure:

In this chapter preparation of tool and work piece materials, properties of the materials and planning of the experiment discussed in details. Experiments were conducted in two phases. In first phase electrode was prepared by W and Cu powder by the P/M method as tool electrode and Al as work piece (WP). During the second phase of the experiment electrode was prepared with TiC and Cu powder and AISI 1020 mild steel as work piece.

3.1 WC-Cu Coating on Al surface using green compact W-Cu electrode

Experimental planning on this stage of the work includes:

1. Preparation of P/M compacted tool electrode by using W and Cu.
2. EDC with a P/M tool electrode on the Al surface using EDM.

3.1.1 Preparation of P/M compact tool electrode by using W and Cu

Electrodes used for EDC was made with mixtures of copper and tungsten at 50:50 wt. %. Here, Cu act as a binder and improve the conductivity of tool. Again Cu helps to braze the compact tool or pellet with mild steel extension. Electrodes consist of two parts; a tool extension part for proper holding the tool electrode in the EDM system which was made with mild steel and a P/M compacted pellet which actually act as electrodes and from which material is eroded and deposited on the work piece surface during the EDC process. For making pellets copper and tungsten powders were mixed together by using mortar and pestle made of ceramic. Powders were compacted at compaction pressures of 150 MPa and 200 MPa by using a compaction die of 12.5 mm diameter. The compacted pellet and tool extension part then brazed together using braze welding process. In this case sintering was not done, since the strength of the compact was enough for EDC. Details of parameters used for tool preparation are shown in Table 1. The PM compacted tool electrodes are shown in Fig.3.

Table 1: Tool Preparation Parameters

Tool Preparation Parameters	Values used
Size of pellet	12.5 mm diameter & 5 mm height
Compaction pressure	150 MPa & 200 MPa
Holding time	2 minutes
Powder proportion	50:50 wt%

Fig.3: W-Cu powder compact tool electrodes with tool extension

Aluminum plate of 3 mm thickness, cut into 25 mm length and 15 mm width was used as work piece. The burrs on the edges were removed by using emery paper (abrasive paper). The work piece was then cleaned with acetone liquid. Before taking the initial weight of the Al work piece, it was dipped in the dielectric to fill the pores present in the workpiece surface.

3.1.2 EDC with P/M tool electrode on Al surface

In order to study the effect of input parameters like peak current (Ip), pulse on time (Ton) and tool compaction pressure (TP) on deposition rate, tool wear rate and micro hardness experiments were conducted with various combinations of parameters setting as per L18 Taguchi design. Electro discharge machines (ELECTRONICA LEADER-1, ZNC version ELEKTRAPULS PS 50 ZNC EZY LOGIC) were used to perform the EDC coating. The experiment setup is shown in Fig.4.

Fig.4: Experimental setup of EDM used for the present EDC process

The experiment was started by keeping powder compacted tool made by W and Cu as anode and Al work piece as cathode. By employing reverse polarity each experiment was performed for 10 minutes. During the electrodischarge process the tool starts eroding and a coating of WC- Cu was deposited on the Al work piece surface.

During the experiment two different types of tools were used; both at the same composition of W: Cu = 50:50 weight% and tool compaction pressure (TP) of 150 MPa and 200 MPa. With each tool 9 experiments were conducted with different peak current (Ip) and pulse on time (Ton) as per the Taguchi experimental design. After performing the experiments effect of TP, IP and Ton were studied and analyzed for deposition rate, tool wear rate and microhardness.

3.2 Experimental design

To optimize the parameters in electro discharge coating (EDC), an experiment design was made. For optimizing the various factors affecting electro discharge coating a design of experiments (DOE) is made by using the Taguchi methodology. DOE techniques will help to find out the effect of individual parameters that could affect the coating developed by EDC.

3.2.1 Taguchi method for parametric design

The traditional experimental design procedures and analysis are time consuming and sometimes expensive, therefore these types of design are not economical. As a remedial measure of all these issues, the Taguchi method used to study the various parameters that are affecting the output with only a small number of experiments. Now a day Taguchi method is widely used in various engineering analyses for understanding the behavior of a particular process. The greatest advantage of this technique is saving the effort related to conducting the experiment, time of experiments and finding out the significant factors easily. Unlike the factorial design, where all possible combinations were checked, Taguchi method tests pairs of combination. The experiment design involves orthogonal arrays to arrange the parameters affecting the process and the levels they should vary. During the analysis if variations were found between the predicted and observed design correction actions can be done. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analyses can be employed to find out the optimum levels and to analyze the effect of EDM parameters on Electro Discharge Coating (EDC). The orthogonal array can be constructed by understanding the number of control factors, their levels, etc. For EDC on Al substrate with the powder compacted tool of W and Cu mixed powders an orthogonal array of L18 was used.

3.2.2 Plan of experiment

Taguchi based analysis has been used to study the effect of three input parameters tool compaction pressure (TP), pulse current (Ip) and pulse on time (Ton) on three important response for EDC process i.e. deposition rate, tool wear rate and micro hardness. In this research 18 experiments were conducted for coating on Al substrate. EDC process parameters are shown in Table 2. Here, 18 no of rows corresponding to the 18 experiments 3 columns corresponding to the three different parameters are shown in Table 3. The parameters like voltage and duty factor was fixed to 40 V, and 50 % respectively. Time of one experiment was considered 10 minutes.

Table 2: EDC Process Parameters for W-Cu tool electrode

Parameters	Level		
	1	2	3
Tool compaction pressure (MPa)	150	200	-
Pulse current (A)	2	3	4
Pulse on time (µs)	100	200	300

Table 3: L18 Orthogonal design for EDC with W-Cu tool electrode

Exp No	Tool compaction pressure (MPa)	Pulse current (A)	Pulse on time (μs)
1	150	2	100
2	150	2	200
3	150	2	300
4	150	3	100
5	150	3	200
6	150	3	300
7	150	4	100
8	150	4	200
9	150	4	300
10	200	2	100
11	200	2	200
12	200	2	300
13	200	3	100
14	200	3	200
15	200	3	300
16	200	4	100
17	200	4	200
18	200	4	300

3.3 Determination of S/N ratio

Taguchi method stresses the study by using response variation and signal to noise ratio, which is helpful to minimize the quality characteristic variation due to uncontrollable parameter. According to the problem and the type of response SN ratio can be calculated mathematically as follows.

The S/N ratio for the larger-the-better is calculated as

$$S/N = -10 \log_{10} \left[\frac{1}{n} \sum \frac{1}{y2} \right] \qquad [2]$$

The S/N ratio for the smaller-the-better is calculated as

$$S/N = -10 \log_{10} [\frac{1}{n} \sum y^2] \quad [3]$$

Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. After calculating the SN ratio for each experiment, the average SN value is calculated for each factor and level. Regardless of the type of characteristics, a greater S/N value represents the best performance.

3.4 Analysis of Variance (ANOVA)

ANOVA is an objective decision modeling tool which is statically based, used for detecting the variation in the average performance of a group of items tested. ANOVA helps to test the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors.

The total sum of squares SST, from the total mean S/N ratio can be calculated as

$$SS_T = \sum_{i=0}^{n} (\eta_i - n_m)^2 \quad [4]$$

Where n is the number of experiments in the orthogonal array and η_i is the grand total sum of squares and n_m is the sum of squares due to mean S/N ratio for the experiment.

The percentage contribution P can be calculated as:

$$P = SS_d / SS_T \quad [5]$$

Where SS_d is the sum of the squared deviations.

The percentage (%) can be then find out from the experimental table is defined as the significant rate of the process parameters of output.

3.5 TiC-Cu Coating on AISI 1020 mild steel

In this second phase of EDC experiment, TiC-Cu coating was deposited on AISI 1020 mild steel surface. Experimental planning on this stage of the work includes:

1. Preparation of P/M compacted tool electrode of TiC and Cu mixture.
2. Experimentation for EDC with TiC-Cu P/M tool electrode on AISI 1020 mild surface using EDM.

3.6 Preparation of P/M compact tool electrode with powder mixture of TiC and Cu

Electrodes used for EDC was made with mixtures of TiC and copper at 60:40, 70:30 and 20:80 wt. %. Powders were compacted at compaction pressures of 300 MPa by using a compaction die of 15 mm.

In this case also there is no requirement of any binder, since the Cu particles act as binding agents. But the strength of the compact prepared is not strong enough since TiC was used which is very brittle and probability of boding with other material is very less. So sintering was done at a temperature of 900^0 C. In order to prevent oxidation inert gas was provided during sintering from a separate cylinder. The parameters used for tool preparation are shown in Table 4. The pellet and tool extension part were then brazed together. The pellets prepared with TiC-Cu after sintering and PM compacted tool electrodes after brazing with tool extension are shown in Fig.5 and Fig.6 respectively.

Table 4: Tool Preparation Parameters for TiC-Cu tool electrode

Tool preparation parameters	Values used
Size of pellet	15 mm diameter,10 mm height
Compaction pressure	300 MPa
Holding time	2 minutes
Powder proportion	TiC: Cu =60:40, 70:30 and 20:80 wt.%

Fig.5: TiC-Cu pellets

Fig.6: TiC-Cu Powder Compacted tool electrodes

AISI 1020 mild steel of 25 mm width and 25 mm length and 5 mm thickness was used as substrate material. The surface of mild steel was smoothen by using surface grinding machine and further by emery paper. The workpiece was then cleaned with acetone before the experiment. Before taking the initial weight mild steel work pieces were dipped in the dielectric to fill the pores present in the workpiece surface so that after experiment an accurate measure can be possible. The AISI 1020 mild steel work piece used for the experiment is shown in Fig.7.

Fig.7: AISI 1080 mild steel work piece

3.6.1 EDC with P/M tool electrode on mild steel surface

In order to study the effect of input parameters like peak current (Ip) and pulse on time (Ton) on coating performances, i.e. deposition rate, tool wear rate, micro hardness and surface roughness experiments were conducted at various conditions. EDC process parameters for this phase of the experiment are shown in Table 5.

Table 5: EDC process parameters for TiC-Cu tool electrode

EDC process parameters	Values
Peak current (Ip)	3,4,5 and 6 A
Pulse on time (Ton)	100, 200 and 300 µs
Voltage (V)	40 V
Duty factor (Tau)	50 %
Time of one experiment	10 minutes

The detailed experimental plan is shown in the Table 6

Table 6: Plan of EDC experiment with TiC –Cu tool electrode

<table>
<tr><th>Exp. No</th><th>Ip</th><th>Ton</th></tr>
<tr><td>1</td><td>3</td><td rowspan="4">100</td></tr>
<tr><td>2</td><td>4</td></tr>
<tr><td>3</td><td>5</td></tr>
<tr><td>4</td><td>6</td></tr>
<tr><td>5</td><td rowspan="2">5</td><td>200</td></tr>
<tr><td>6</td><td>300</td></tr>
</table>

3.6.2 Measurement of deposition rate and tool wear rate

The deposition rate of the composite layer was calculated by measuring the weight of substrate before and after the experiment. The difference in weight indicated the amount of material transferred from the tool to work-piece or substrate material. The deposition rate (DR) was calculated by considering the experimental time as per Eqn. 6.

$$\text{DR} = \frac{\text{WP wt before expt} - \text{WP wt after expt}}{\text{Time of experiment}} \qquad [6]$$

Similarly the tool wear rate (TWR) was also measured by dividing the difference between the initial and final weight of the tool with experimental time as per Eqn. 7.

$$\text{TWR} = \frac{\text{Tool wt before expt} - \text{Tool wt after expt}}{\text{Time of experiment}} \qquad [7]$$

3.7 Preparation of samples for optical images and micro hardness

After the experiment conducted, the work pieces were cut with the help of wire EDM so that the cross section of the coated sample is obtained. To measure the micro hardness of the coating and to study the micro structure of the coating metallography polishing was done. To hold the cut work piece during polishing, samples were mounted with resin. Polishing was done with abrasive papers of different grades of 220, 600, 1200 grain size and finally diamond polishing was done. The polished surface was then cleaned with acetone before measuring micro hardness and micro structure study.

Micro hardness of each sample was measured by using the Vickers micro hardness tester (LECO Micro hardness Tester (LM248AT)). The testing conditions were taken dwell time of 10 seconds and at 50 gf. For each samples 6 values were taken and then average of those value was calculate. The micro structure of the coating obtained was studied by using the image obtained from the optical microscope (AXIOCAM Arc 5s).

Chapter 4

Results and Discussions:

In this chapter experimental results obtained by conducting EDC on Al surface with WC-Cu and on AISI 1020 mild steel surface with TiC-Cu have been discussed.

4.1 EDC on Al surface by using P/M tool electrode of W and Cu

The effect of different parameters on deposition rate, tool wear rate and micro hardness were studied by conducting experiments which was designed on the basics of Taguchi L18 design. Analysis of S/N ratios and ANNOVA was done by calculating the numerical values manually. The effect of various parameters was found by plotting graphs calculating the mean values of the responses. Table 7 shows the experimental data for deposition rate, tool wear rate and average micro hardness. WC-Cu coated Al work pieces at different input parameters are shown in Fig.8.

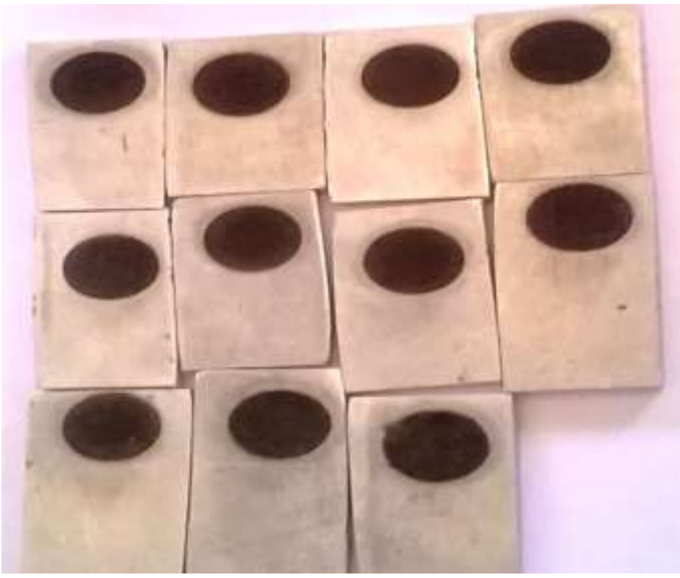

Fig.8: WC-Cu coated Al work pieces from Exp No: 9 -18

Table 7: Experimental data for deposition rate, tool wear rate and average micro-hardness for EDC on Al surface using W-Cu P/M tool electrode

Ex No	Tool compaction Pressure (MPa)	Peak current (Ip) (A)	Pulse on Time (μs)	Initial work piece weight (g) (A1)	Final work piece weight (g) (A2)	Deposition rate (g/min) A2-A1/time	Initial tool weight (g) (B1)	Final tool weight (g) (B2)	Tool wear rate (g) B1-B2/time	Avg. Micro Hardness (HV)
1	150	2	100	5.005	5.077	0.0072	44.474	43.864	0.061	276.9
2	150	2	200	5.396	5.463	0.0067	43.864	42.986	0.0878	204.91
3	150	2	300	5.229	5.285	0.0056	42.977	42.22	0.0757	286.97
4	150	3	100	4.732	4.888	0.0156	42.216	40.978	0.1238	280.23
5	150	3	200	4.999	5.16	0.0161	40.977	39.548	0.1429	312.61
6	150	3	300	5.146	5.288	0.0142	39.522	38.478	0.1044	294.93
7	150	4	100	4.812	4.949	0.0137	49.914	48.973	0.0941	318.83
8	150	4	200	5.055	5.259	0.0204	46.813	45.266	0.1547	336.55
9	150	4	300	5.258	5.413	0.0155	48.027	46.46	0.1081	351.43
10	200	2	100	5.518	5.609	0.0091	44.46	43.809	0.0651	420.85
11	200	2	200	5.448	5.564	0.0116	43.762	42.777	0.0985	452.38
12	200	2	300	5.132	5.237	0.0105	42.656	41.901	0.0755	471.33
13	200	3	100	5.153	5.247	0.0094	50.427	49.584	0.0843	482.11
14	200	3	200	5.42	5.578	0.0158	41.711	40.486	0.125	479.73
15	200	3	300	6.092	6.203	0.0111	49.467	48.605	0.0862	430.18
16	200	4	100	6.576	6.69	0.0114	40.353	39.236	0.1117	478.9
17	200	4	200	6.099	6.243	0.0144	48.494	47.04	0.1454	491.86
18	200	4	300	5.378	5.489	0.0111	46.82	45.74	0.108	499.85

4.2 Effect of different parameters on Deposition Rate

The difference in work piece weight divided by the time of the experiment will give the deposition rate on the work piece. The effect of various input parameters is explained with the help of graphs plotted after taking the mean value of the responses.

4.2.1 Effect of tool compaction pressure

Effect of compaction pressure on deposition rate has been studied and analyzed by varying the compaction pressure of tool electrode from 150 MPa to 200 MPa for same powder composition of W:Cu =50:50 wt %. Effect of tool compaction pressure for the mean value of deposition rate is shown in Fig.9. From the graph it is clear that when compaction pressure is increasing from 150 MPa to 200 MPa the deposition rate is slightly decreasing. So it can be said that a larger material deposition rate can be obtained by using a tool electrode prepared with lower compaction pressure. This is because at higher compaction pressures the powder mixture of tool materials is firmly bonded and the bond between the powder particles is strong enough to reduce the material transfer rate from the powder compacted tool electrode to Al work piece.

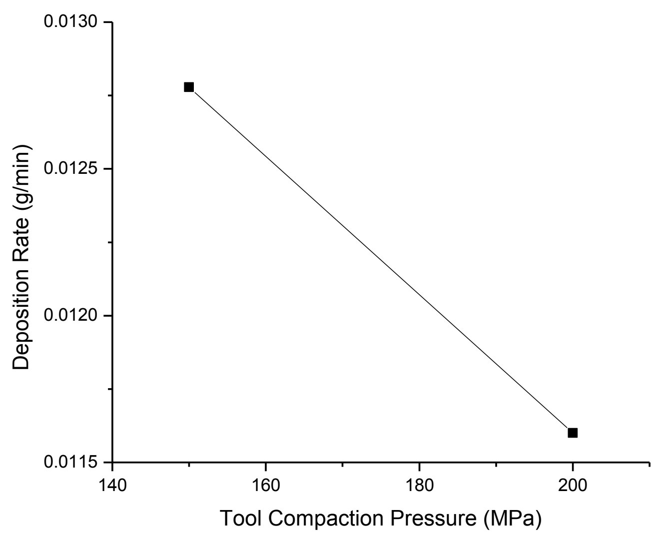

Fig.9: Effect of tool compaction pressure on deposition rate for means

4.2.2 Effect of peak current (Ip)

Effect of current on the mean value of deposition rate has been studied by varying current from 2A to 4 A. At a compaction pressure of 150 MPa and 200 MPa the different current used for studying the variation in deposition rate are 2, 3 and 4 A. From the Fig.10 it is clear that when current is increasing from 2 to 3A the deposition rate is also increasing. The same trend is followed when the current further increased to 4 A, even though the increase in deposition rate is not that much increased as compared to the increase from 2A to 3A. The reason is that at high peak current more material is disintegrated from the powder compacted tool electrode and deposited on the substrate surface. At high current due to strong spark there is a possibility of removal of some pre-deposited coating layer or substrate material, which causes an reduction in deposition rate.

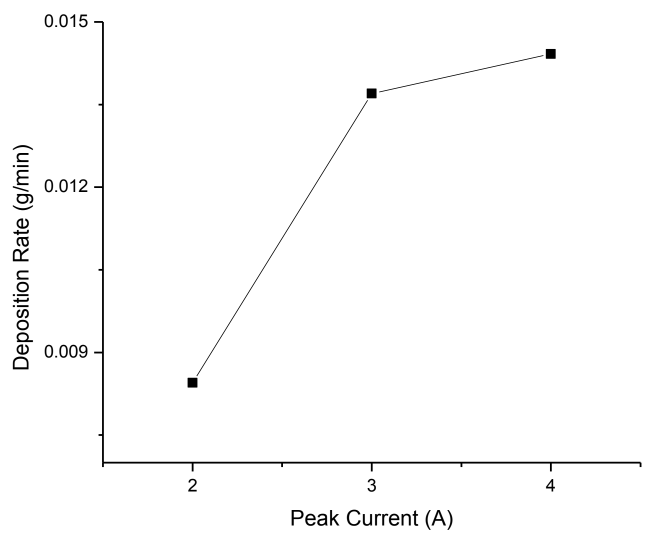

Fig.10: Effect of peak current on deposition rate for means

4.2.3 Effect of pulse on time (Ton)

Effect of Ton on the mean value of deposition rate is plotted in Fig.11. When the pulse on time increases from 100 to 200µS the deposition rate is also increasing. At higher pulse on time, it has a more dominant effect on input energy. Due to the higher temperature generated more powder material is eroded from the electrode. But it is found that when pulse on time is further increased to 300µs the deposition rate shows a decreasing trend. At higher pulse on time the coating obtained is more rough and brittle and hence most of the material deposited is not properly bonded to the Al work piece.

The optimum parameters for higher deposition rate are found for using a tool electrode prepared with 150MPa compaction pressure, 3A peak current and 200µs pulse on time.

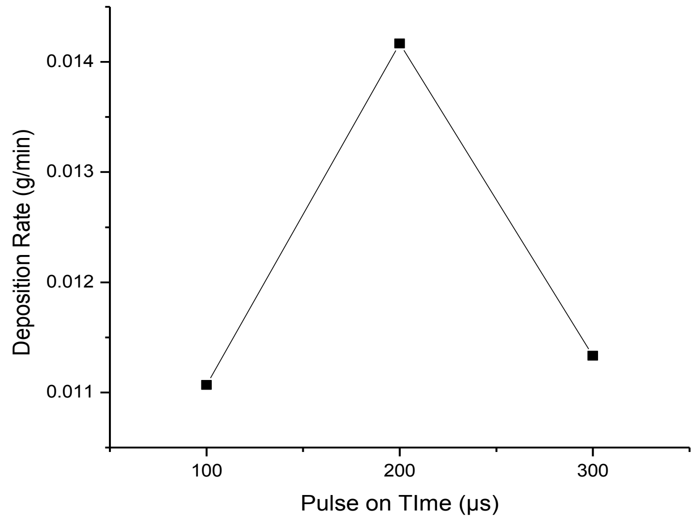

Fig.11: Effect of pulse on time on deposition rate for means

4.3 Effect of different parameters on Tool wear rate

4.3.1 Effect of tool compaction pressure

Effect of tool compaction pressure on the mean tool wear rate is plotted in Fig.12. It is clear from the graph plotted for means that, the tool wear rate is more for using electrode prepared at lower compaction pressure, i.e. 150MPa and less for tool prepared at higher compaction pressure i.e. 200MPa. This is because of the lower binding energy of the powder particles at low compaction pressure, which enhances the erosion of tool material for electrode prepared at lower compaction pressure.

4.3.2 Effect of peak current (Ip)

Effect of peak current on the mean value of the tool wear rate is shown in Fig.13. The various current used are 2, 3 and 4 A for using electrode prepared with compaction pressures of 150 MPa and 200 MPa respectively. The tool wear rate increases with increase in peak current during the EDC process. The higher current has a dominant effect on input energy and hence more temperature is generated in the tool material and more material is melted and eroded from the tool electrode and hence tool wear is increased.

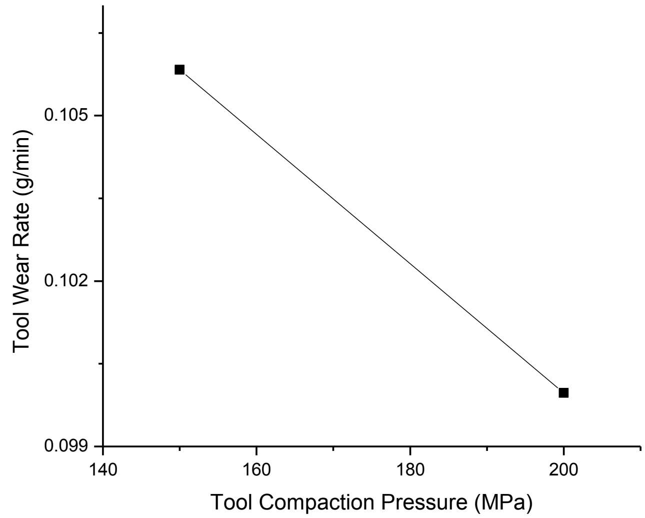

Fig. 12: Effect of tool compaction pressure on tool wear rate for means

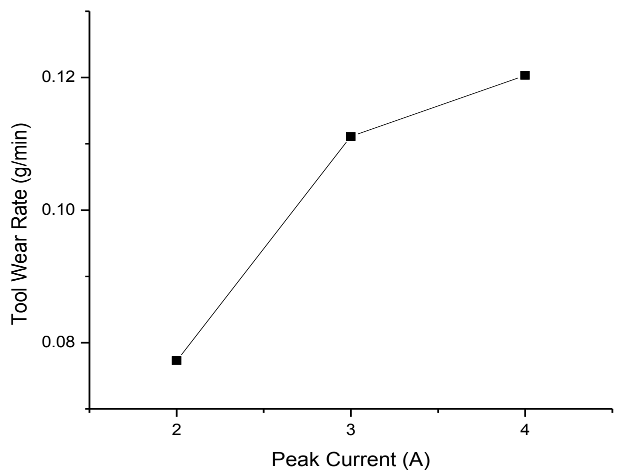

Fig.13: Effect of peak current on tool wear rate for means

4.3.3 Effect of pulse on time (Ton)

Effect of Ton on the mean value of the tool wear rate is shown in Fg.14. The pulse on time has also a significant influence on tool wear rate and it is evident from the fact that the tool wear rate is increased when pulse on time is increasing from 100 to 200 µS. Due to the strong spark generated during discharge at 200 µS pulse on time; more tool wear rate is observed. But when pulse on time is further increased to 300µS the tool wear is rapidly decreased. The main reason for this, at high pulse on time more heat is generated and hence the diameter of the discharge has increased. But energy density on the discharge spot will reduce and there will be an undesirable heat loss which will not contribute to material removal from tool and hence the tool wear rate will reduce (Alidoosti et.al (2013)). The optimum parameter combination of lowest tool wear rate is tool electrode compaction pressure 150MPa, applied peak current 4A and pulse on time of 200 µs during EDC.

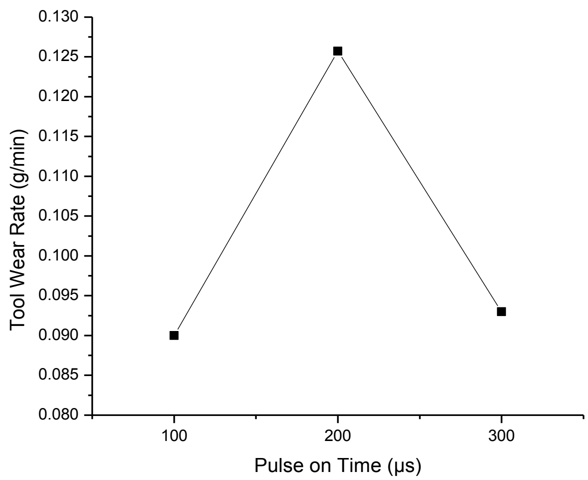

Fig.14: Effect of Ton on tool wear rate for means

4.4 Effect of different parameters on average microhardness

4.4.1 Effect of tool pressure

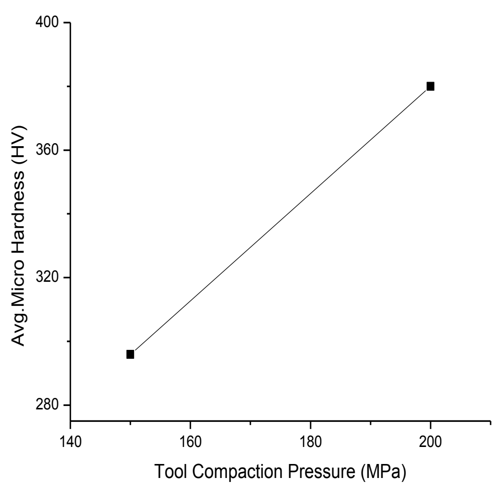

Fig.15: Effect of tool pressure on average micro hardness for means

Effect of tool pressure on average micro hardness is shown in Fig.15. From the graph plotted, it is evident that lower micro-hardness value was obtained on the coating with tool prepared at a tool compaction pressure of 150 MPa. When the tool compaction pressure increases from 150 MPa to 200 MPa the micro hardness is also increasing. This may be due to fact that, for coating deposited with a tool which is prepared with higher compaction pressure the layer created at a slow rate and chances of pore formation is less. Therefore a higher microhardness value achieved than the coating processed with tool prepared at low compaction pressure where chances of pore formation are more.

4.4.2 Effect of pulse current (Ip)

The effect of Ip on average micro hardness is shown in Fig.16. It is observed that coating deposited with high peak current the average micro-hardness is also high. The lowest micro hardness is observed at a pulse current of 2 A and these average micro hardness value increases with increase of current. This is may be due the fact that at high current deposition on the Al surface is increasing and hence average micro hardness is also increasing.

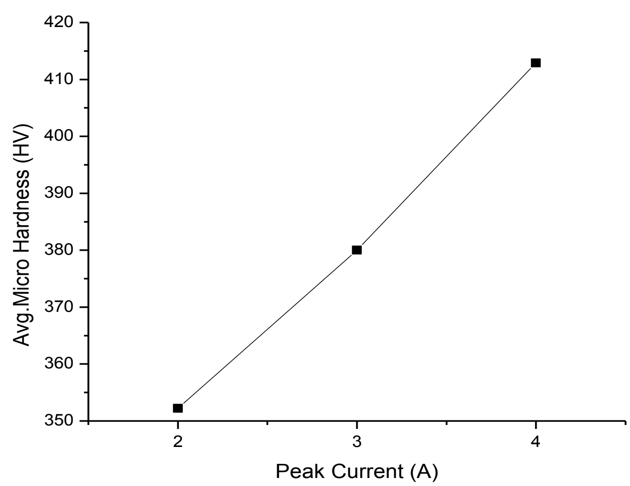

Fig.16: Effect of peak current on average micro hardness for means

4.4.3 Effect of pulse on time (Ton)

The effect of Ton on average micro hardness is shown in Fig.17. Average micro hardness of coating is increasing with the increase in Ton values. This is due to the fact that when Ton increases more material is removed from the tool and thicker coating is obtained at the Al work piece surface which gives a higher hardness value than the coating processed at low Ton time.

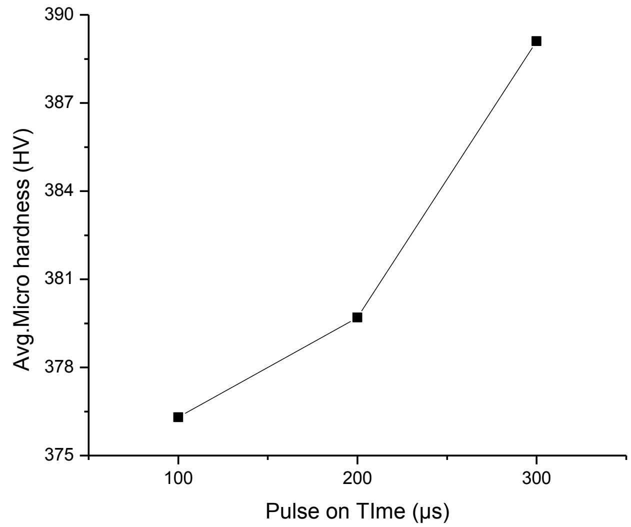

Fig.17: Effect of pulse on time on average micro hardness for means

4.5 Analysis of S/N ratio

4.5.1 S/N ratios for deposition rate

Table 8: S/N ratio values for Deposition rate by factor level

Level	Tool Pressure	Ip	Ton
1	-18.62	-21.75	-19.41
2	-18.84	-17.44	-17.45
3		-17.01	-19.32
Delta	0.22	4.74	1.96
Rank	3	1	2

Herethe S/N ratio was considered "larger is better" for deposition rate. From the Table 8 it is clear that the significant factor that influencing deposition rate is Ip and then Ton. Tool compaction pressure had less influence on deposition rate as compared to other two factors.

4.5.2 S/N ratios for tool wear rate

Table 9 shows the S/N ratios, "smaller is better" for tool wear rateby factor level. As like deposition rate the primary factor influencing tool wear is Ip. Ton also have a significant influence, but less than that of Ip. The least affecting factor is tool compaction pressure; the delta value of this factor is very small which indicating its influence is less.

Table .9: S/N ratios for Tool wear rate by factor level

Level	Tool Pressure	Ip	Ton
1	0.1584	-2.357	-1.2030
2	-0.2506	0.7490	1.8031
3		1.4698	-0.7383
Delta	0.4090	3.8269	3.0061
Rank	3	1	2

4.5.3 S/N ratios for micro hardness

Signal to Noise Ratios for “larger is better” in the case of micro hardness is shown in Table 10. Unlike other two responses the primary influencing factor for micro hardness is tool compaction pressure followed by Ip and Ton.

Table 10: S/N ratios for Micro hardness by factor level

Level	Tool Pressure	Ip	Ton
1	-49.33	-50.55	-51.27
2	-53.38	-51.37	-51.21
3		-52.16	-51.60
Delta	4.05	1.61	0.39
Rank	1	2	3

4.6 Analysis of Variance (ANOVA)

The ANOVA table is created for 95 % confidence level. The P-value reports the significance level (suitable and unsuitable) for deposition rate, tool wear rate and avg. micro-hardness in Table 11, Table 12 and Table 13 respectively. Percent (%) is defined as the significance rate of the process parameters on the deposition. The percent numbers depict that the tool pressure, Ip and Ton has significant effects on the deposition rate. It can observe from the table the tool pressure, Ip and Ton affecting the deposition rate by 0.142 %, 55.01 % and 9.81 % respectively.

Table 11: ANOVA for deposition rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage
Tool Pressure	1	0.214	0.2140	0.2140	0.05	0.829	0.142
Ip	2	82.391	82.3908	41.1954	9.42	0.003	55.01
Ton	2	14.695	14.695	7.3476	1.68	0.227	9.81
Residual error	12	52.457	52.457	4.3715			35.02
Total	17	149.757					

From the ANOVA for S/N ratios in case of tool wear rate the percent numbers shown that they has significant influence on response. It can observe that the tool pressure, Ip and Ton affecting the tool wear rate by 0.807 %, 53.21 % and 33.69 % respectively.

Table 12: ANOVA for tool wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage
Tool Pressure	2	0.7526	0.7526	0.7526	0.79	0.392	0.807
Ip	2	49.6242	49.6242	24.8121	26.00	0.000	53.21
Ton	2	31.4226	31.4226	15.7113	16.46	0.000	33.69
Residual Error	12	11.4512	11.4512	0.9543			12.28
Total	17	93.2506					

From the ANOVA for S/N ratios in case of tool wear rate, the percent numbers shown that they have significant influence on response. It can observe that the tool pressure, Ip and Ton affecting the tool wear by 0.807 %, 53.21 % and 33.69 % respectively.

Table 13 shows the ANOVA for S/N ratios in the case of micro hardness. As found earlier the most significant factor influencing the response is tool compaction pressure. It's affecting the micro hardness by 80.58 %. Which is followed by Ip and Ton as they contribute 8.56 % and 0.5821 % on the average micro hardness obtained.

Table 13: ANOVA for micro hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage
Tool Pressure	1	73.115	73.115	73.115	101.48	0.000	80.58
Ip	2	7.7672	7.7672	3.8836	5.35	0.022	8.56
Ton	2	0.5282	0.5282	0.2641	0.36	0.703	0.5821
Residual error	12	8.7161	8.7161	0.7263			9.61
Total	17	90.7320					

4.7 X- Ray Diffraction (XRD) Analysis

XRD analysis was done to identify different material phase present in the deposited coating. In this case in order to analyze the effect of different parameters and surface composition XRD analysis has been used. XRD graph obtained with the aid of Phillip's X pert high score software is helpful in this regard. XRD analysis is done for samples with different parameters are shown in Fig.18, Fig.19 and Fig.20.

From the graphs it is found that W, WC and Cu are present on the coated surface. From the intensity of the peak of the graphs it is observed that at 3A more amount of W and WC in the coating surface as compared to current of 2A. So as current increases amount material deposited is increasing. Similarly the effect of tool compaction pressure can also be analyzed. The effect of tool compaction pressure can be analyzed from Fig.19 and Fig.20. It is observed that the amount of W and WC decreases when tool compaction pressure increases from 150 MPa to 200 MPa.

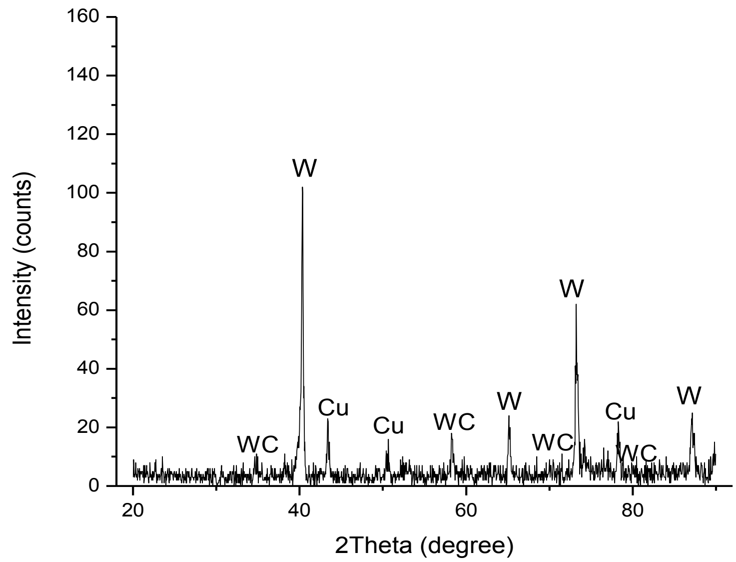

Fig.18: XRD graph of Sample 3 with Ip= 2A, Ton= 300μs and TP= 150MPa

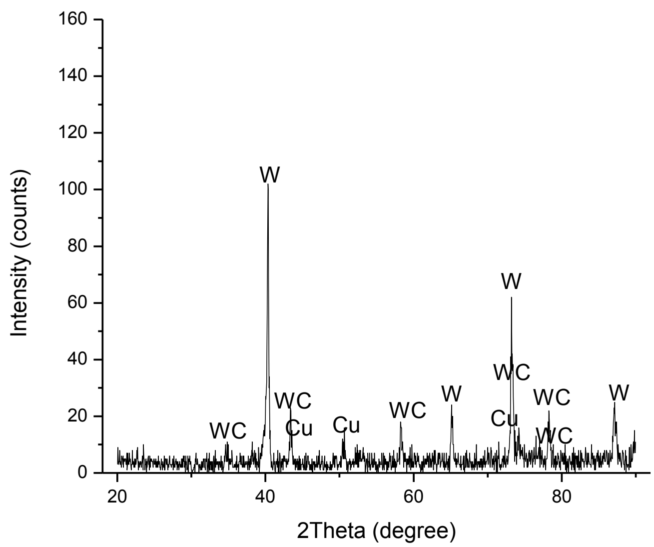

Fig.19: XRD graph of Sample 4 with Ip= 3A, Ton= 100μs and TP= 150MPa

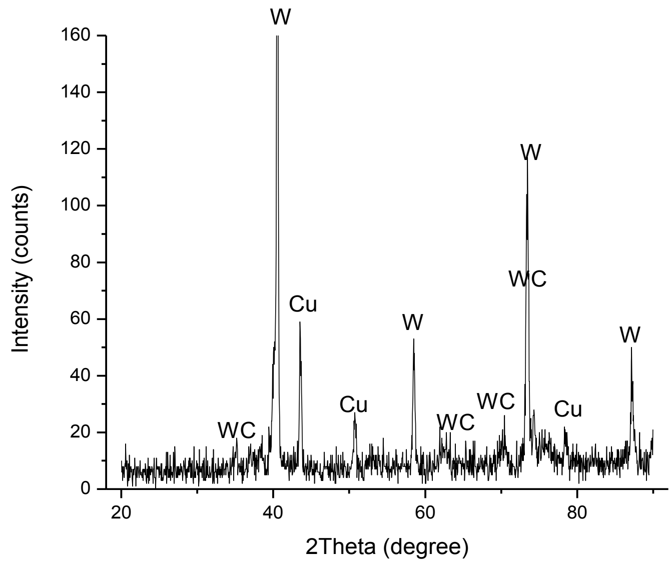

Fig.20: XRD graph of Sample 10 with Ip= 2A, Ton= 100µs and TP= 200MPa

4.8 Optical microscopy images of the coating

The macro structure of the coating has been studied by using the image obtained from the optical microscope (AXIOCAM Arc 5s). Coating layer is visible in between the mounting and Al work piece. From the coating layer two different shaded portions are visible. Dark black portion and in between that white reflecting area. Here this dark area may tungsten carbide and lighter area is showing the copper.

4.8.1 Effect of compaction pressure

Optical microscopy images of coatings produced, with same peak current of 4 A and pulse on time of 300 µs but tool prepared at different compaction pressures of 150 MPa and 200 MPa respectively are shown in Fig.21 and Fig.22. It is clear from the figures that, when tool compaction pressure is relatively low, during the EDC process tendency of removal or disintegration of tungsten and copper mixture from tool electrode increases, which after reaction with decomposed carbon from dielectric produces tungsten carbide and deposited a relatively thicker layer on aluminum substrate.

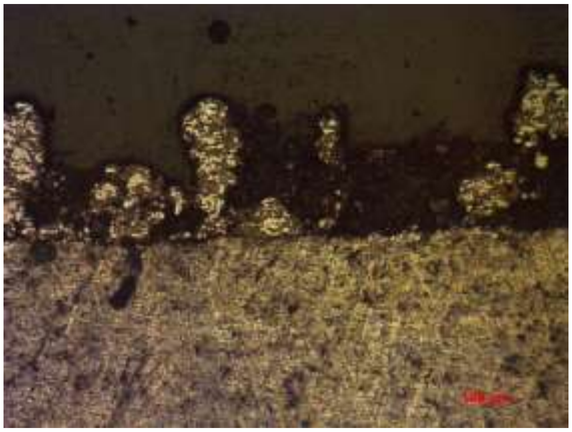

Fig.21: Optical image of sample 9 with Ip= 4 A, Ton= 300µs and TP= 150 MPa, under 10 X magnification

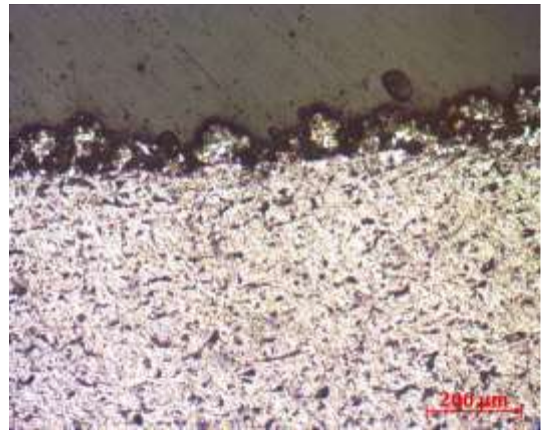

Fig.22: Optical image of sample 18 with Ip= 4 A, Ton= 300µs and TP= 200 MPa, under 10 X magnification

4.8.2 Effect of peak current

Fig.23, 24 and 25, shows the optical microscopy images of the EDC coating for samples 10, 13 and 16, which were performed with same compaction pressure and pulse on time but with different current of 2A, 3A and 4A respectively. From the figure it is found that Sample 10 with a current of 2 A has a less coating layer that compared to the coating layer of sample 13 with a current of 3 A and sample 16 with 4A. High current setting increases the discharge between tool and work piece due to negative polarity and most amount of material disintegrate from the tool electrode and deposited on the work piece.

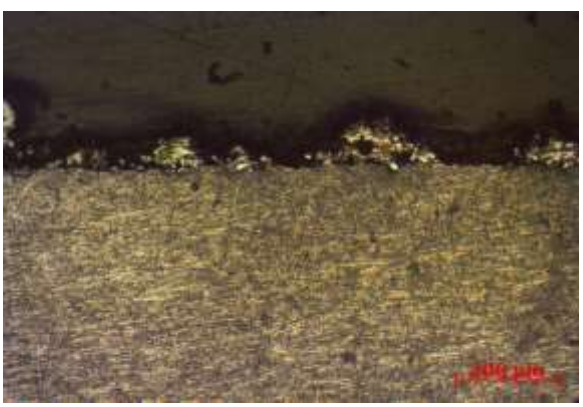

Fig.23: Optical image of sample10 with Ip= 2 A, Ton= 100µs and TP= 200 MPa under 10 X magnification.

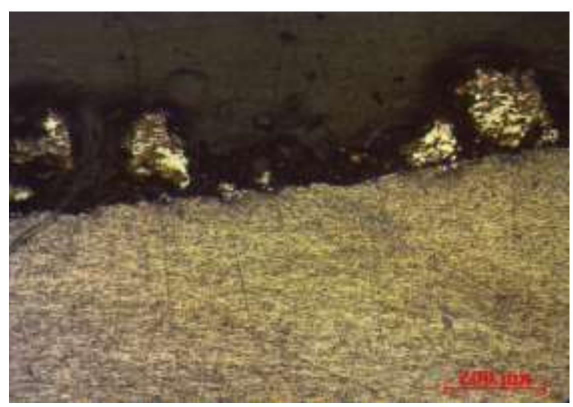

Fig.24: Optical image of sample13 with Ip= 3 A, Ton= 100µs and TP= 200MPa, under 10 X magnification

Fig.25: Optical image of sample16 with Ip= 4 A, Ton= 100μs and TP= 200 MPa under 10 X magnification.

4.8.3 Effect of pulse on time

From the Fig.26, Fig.27 and Fig.28 shows the optical microscopy images of the WC-Cu coating on Al at the cross section for sample prepared with Ip= 3A and Ton of 100 μs, 200 μs and 300 μs respectively. In all three cases, the tool electrode used was prepared with compaction pressure of 200 MPa. From the images it is observed that the thickness of the deposited coating is maximum for 200 μs pulse duration. Earlier analysis of deposition rate also had shown a similar effect.

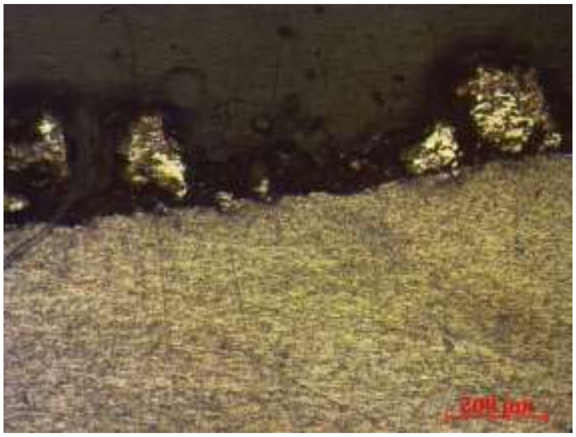

Fig.26: Optical image of sample 13 with Ip= 3 A, Ton= 100μs and TP= 200 MPa, under 10 X magnification.

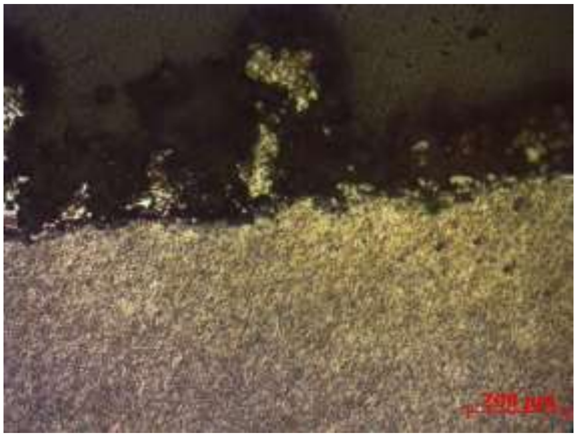

Fig.27: Optical image of sample 14 with Ip= 3 A, Ton= 200μs and TP= 200 MPa, under 10 X magnification

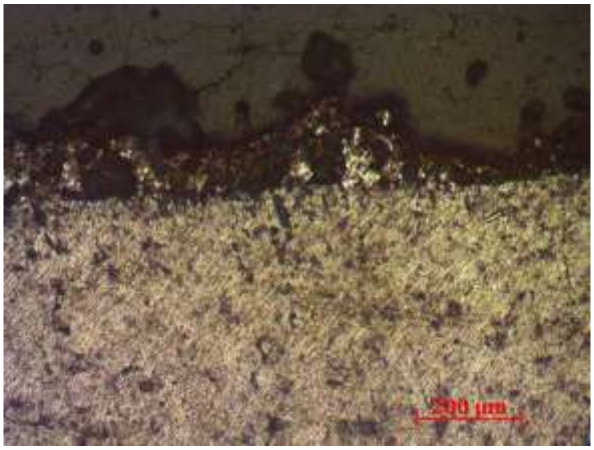

Fig.28: Optical image of sample 15 with Ip= 3 A, Ton= 300μs and TP= 200 MPa, under 10X magnification

4.9 EDC coating on AISI 1020 steel by using the P/M tool of TiC-Cu

In this phase of experiment titanium carbide- copper composite coating deposited on AISI 1020 steel by EDC process. Powder mixture of TiC and Cu in different weight% of 60:40, 70:30 and 80:20 used for tool electrode preparation. But those tool electrodes with 70:30wt% and 80:20 wt% not properly worked during EDC. So for the experiments, tools used were prepared with the same composition of TiC: Cu = 60:40 weight% and tool compaction pressure (TP) of 300 MPa. The experiment is started by keeping the powder compacted tool electrode made of TiC and Cu as anode and steel work piece as cathode. By employing reverse polarity experiment is started and run for 10 minutes. During the EDC process it is observed the tool starts eroding and a layer of TiC- Cu is deposited on the steel work piece surface. With this tool, 6 experiments were conducted with different peak current (Ip) and pulse on time (Ton). So the effect of tool compaction pressure (TP), Ip and Ton are studied. Voltage and duty factor was fixed to 40 V and 50%, respectively. Experimental data for deposition rate, micro hardness and surface roughness are shown in Table 14. TiC-Cu coated steel work pieces are shown in Fig.29.

Table 14: Experimental data for deposition rate, micro hardness and surface roughness

Exp.no	Ip (A)	Ton (µs)	Initial work piece weight (g) (A1)	Final work piece weight (g) (A2)	Deposition Rate A2-A1/time (g/minute)	Micro Hardness (HV)	Average surface roughness Ra $_{avg}$ (µm)
1	3	100	26.311	26.322	0.0011	1535.58	5.035
2	4	100	24.343	24.351	0.0008	1876.17	6.64
3	5	100	27.093	27.099	0.0006	1945.9	7.371
4	6	100	23.847	23.854	0.0007	2268.83	7.596
5	5	200	26.347	26.356	0.0009	2143.47	9.21
6	5	300	24.672	24.678	0.0006	2396.5	9.31

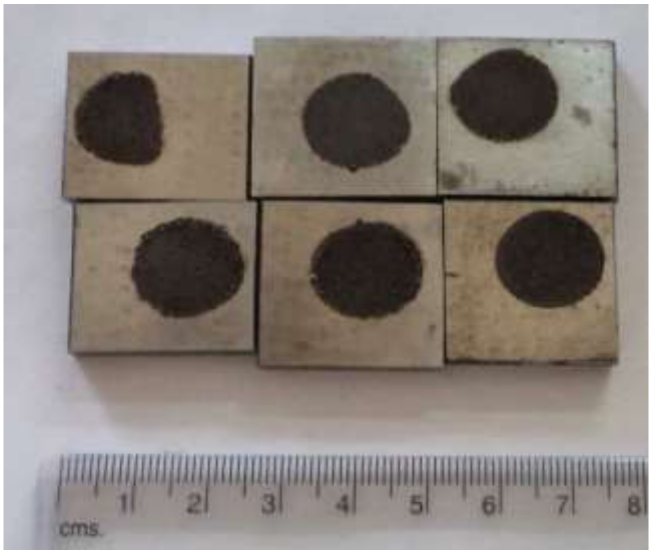

Fig.29: TiC-Cu coated AISI 1020 mild steel with different current and pulse on time during EDC process

4.10 Effect of different parameters on deposition rate

4.10.1 Effect of peak current (Ip)

The effect of Ip on deposition rate during EDC of TiC-Cu coating on steel substrate has been studied for peak current of 3 to 6 A by keeping Ton fixed at 100 µs and plotted in Fig.30. From the graph a decreasing trend of deposition rate with increase in peak current can be observed for 3 to 5 A and then deposition rate is again found increases up to peak current 6 A. Even though the trend is decreasing it can see from the graph that the variation is too small for deposition rate, hence the effect of the current is minimized here. The reason for reduced deposition rate may be, at high peak current along with deposition some removal of workpiece material also took place. As the current increases, may be due to TiC-Cu tool electrode and mild steel work piece combination material removal become larger than the deposition rate. Therefore, overall deposition becomes decreases with the increase of current.

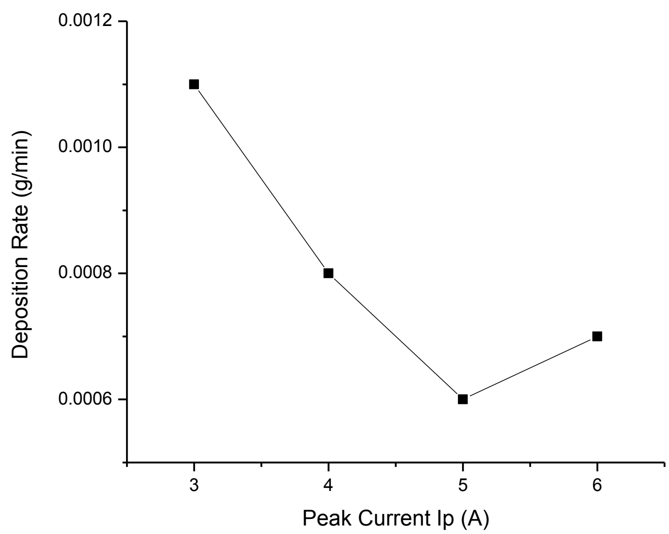

Fig.30: Variation of deposition rate (g/min) with Ip(A) during EDC using TiC:Cu tool electrode at Ton of 100µs

4.10.2 Effect of pulse on time (Ton)

The effect of the Ton during the EDC process for deposition rate has been studied by varying it from 100 to 300 µs by keeping Ip as 5A and plotted in Fig.31. It is observed that with increase in Ton from 100 to 200 μs, the deposition rate is also increasing. It is due to the fact that the dominant effect of input energy. At higher Ton more spark is generated and more material is deposited. But when Ton is further increased to 300 μs the deposition rate is reduced. At high Ton more heat is generated and hence the diameter of discharge has increased. But the energy density on discharge spot may reduce and there may be an undesirable heat loss which cannot contribute to material removal from tool and hence the deposition rate can be reduced (Alidoosti et.al (2013)).

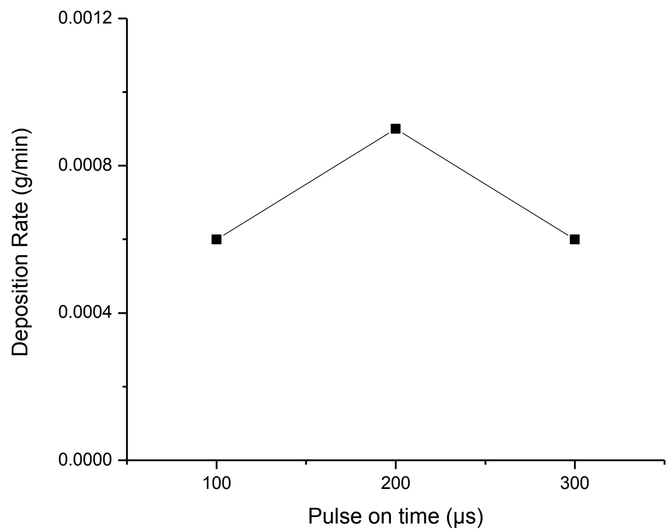

Fig.31: Variation of deposition rate (g/min) with Ton (μs) during EDC using TiC-Cu tool electrode at Ip of 5 A

4.11 Effect of different parameters on Surface Roughness

Surface roughness of the coating were measured by using a Talysurf. The measurement was done at different position of the surface coating so that an average value of surface roughness (Ra_{avg}) can be calculated and then plotted against peak current and pulse on time. The value of surface roughness of different samples are given in Table 14.

4.11.1 Effect of Ip on surface roughness

Average R_a value for coated samples are plotted against Ip used for deposit the coating on steel substrate is shown in Fig.32. It is found that with respect to the increase in current the average value of surface roughness is also increasing. The reason for this increment is at high current due to strong spark there may be a possibility of removal of some pre-deposited coating layer or substrate material.

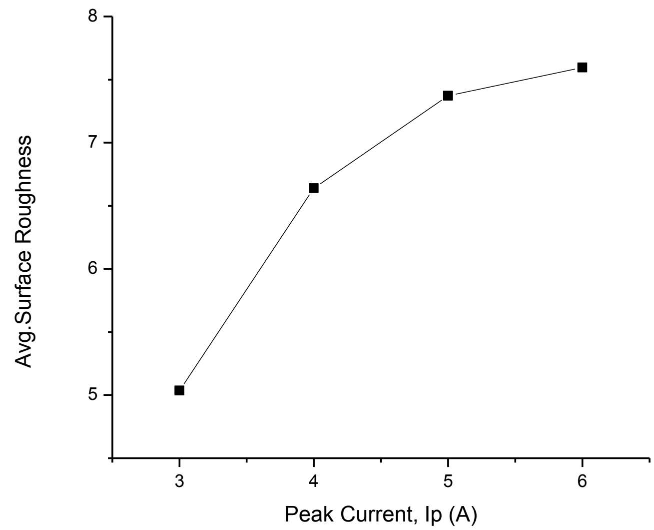

Fig.32: Variation of Average surface roughness (μm) with Ip (A) during EDC using TiC-Cu tool electrode at Ton of 100 μs

4.11.2 Effect of Ton on surface roughness

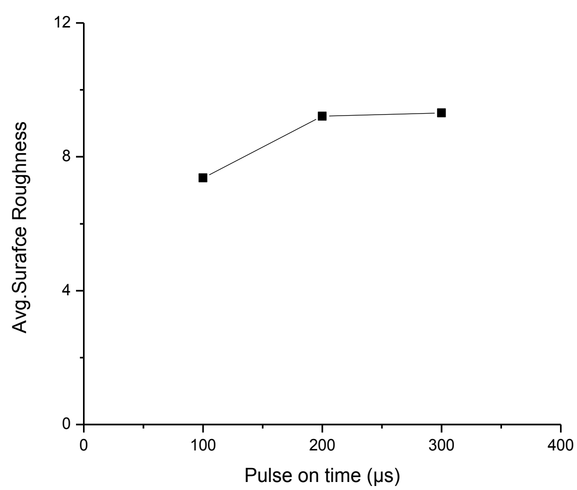

Fig.33: Variation of Average surface roughness (μm) with Ton (μs) during EDC using TiC-Cu tool electrode at Ip of 5

Similarly effect of Ton on surface roughness is plotted in Fig.33. From the plot it is observed that when Ton increases from 100 to 300 μs the surface roughness is also increased. This is due to its dominant effect of input energy, due to strong pulse generated at higher Ton and more material is deposited. Since the deposition rate is higher at higher Ton, the surface became coarser.

4.12 Effect of different parameters on average microhardness

Micro hardness for each sample were measured and average value of micro hardness was calculated and plotted against different process parameters.

4.12.1: Effect of peak current (Ip)

The effect of Ip on micro hardness has been studied by varying Ip from 3 to 6 A by keeping other parameters constant as shown in Fig.34. Average micro hardness value for coating found in the range of 1500 HV to 2400 HV, which is quite high compared to the hardness of substrate material. From the figure it is clear that with increase in peak current average micro hardness value increasing. At high current the coating formed may be not uniform, that's why even though the deposition rate reduces, the micro hardness is increasing.

4.12.2 Effect of pulse on time (Ton)

Average micro harness value for coating processed with constant current and different Ton value (100 to 300 μs) has been plotted in Fig.35. From the graph it is observed that at higher Ton the micro-hardness of the surface coating obtained is very high. It is already found that deposition rate is increasing with Ton and hence more material may be firmly bonded to the mild steel surface at higher Ton.

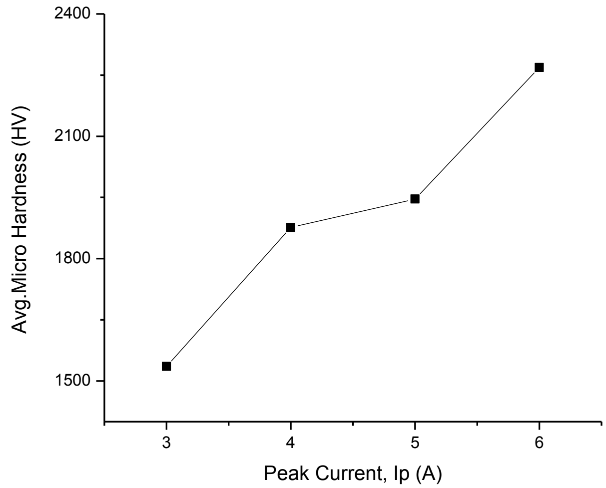

Fig.34: Variation of avg.micro hardness (HV) with Ip(A) during EDC using TiC:Cu tool electrode at Ton of 100µs

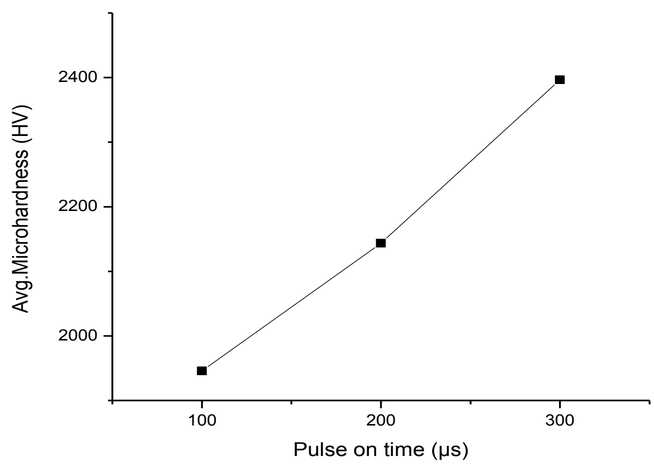

Fig.35: Variation of Average Micro hardness (HV) with Ton (µs)) during EDC using TiC-Cu tool electrode at Ip of 5A

4.13 X- Ray Diffraction analysis of AISI 120 steel coated with TiC and Cu

The XRD graphs for the coating processed with different input parameters are shown in Fig.36, 37 and 38. From the XRD analysis peaks were analyzed and presence of TiC and Cu on the AISI 1020 steel coated surface can be observed. During discharge process TiC and Cu from the tool electrode eroded and deposited on the mild steel workpiece. From the graph the effect of the input parameters can be analyzed by comparing the graphs for different samples. However, no significant change of phases due to change of current and pulse on time during EDC process has been observed.

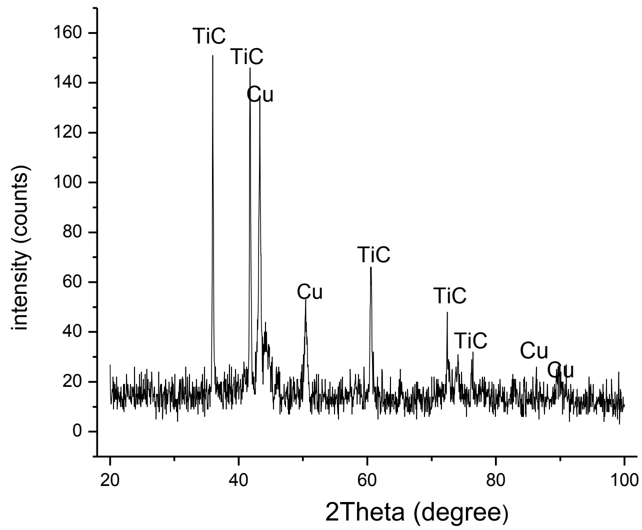

Fig.36: XRD graph of AISI 1020 steel coated with Ti and Cu at Ip= 3A, Ton= 100μs and TP= 300MPa

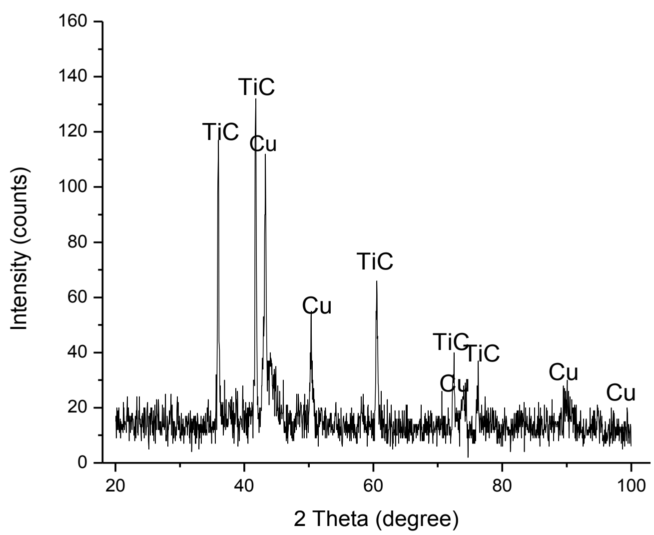

Fig.37: XRD graph of AISI 1020 steel coated with Ti and Cu at Ip= 4A, Ton= 100μs and TP= 300MPa

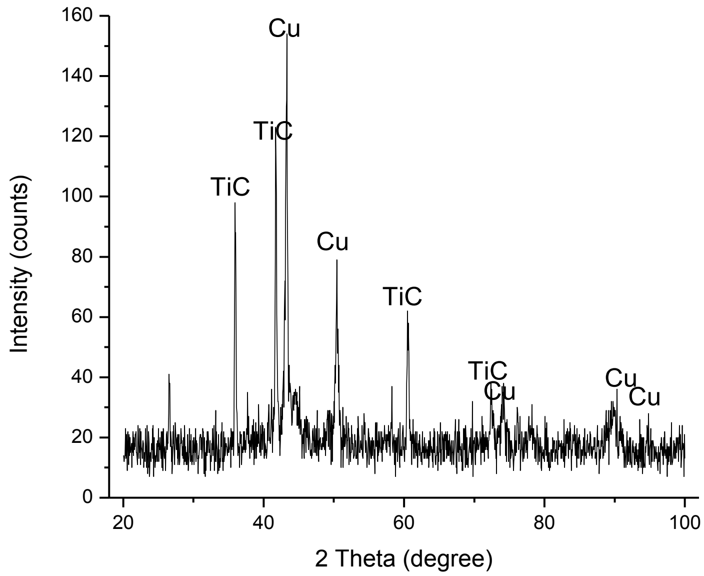

Fig.38: XRD graph of AISI 1020 steel coated with Ti and Cu at Ip= 5A, Ton= 300μs and TP= 300MPa

4.14 Optical microscopy images of AISI 1020 mild steel coated with TiC-Cu

Effect of coating is studied with help of image took from optical microscope. Coating is found in between mounting and steel substrate. From the coating layer two different portions are visible; a darker area and in between that gray area. The dark area may be TiC and gray area may be copper.

4.14.1 Effect of peak current

Optical microscopy images of TiC-Cu coating for samples 1, 2 and 3 which was performed at Ton of 100μs and Ip of 3, 4 and 5A are shown in Fig.39, 40 and 41. A tool compaction pressure of 300 MPa was used for both the samples. As the current increases, may be material removal becomes larger than the deposition and hence produces coatings of relatively lesser thickness at higher peak current.

Fig.39: Optical image of sample 1 with Ip= 3A, Ton= 100µs and TP= 300 MPa, under 10 X magnification.

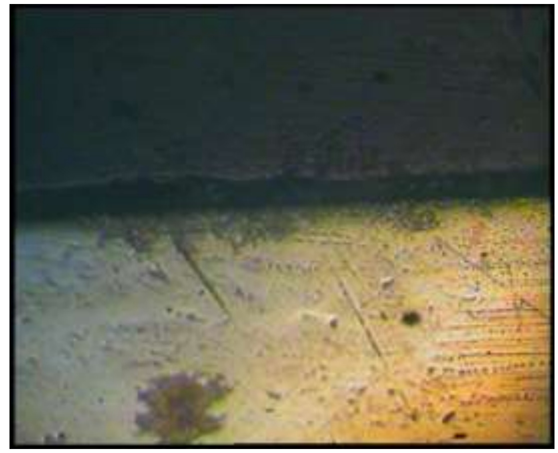

Fig.40: Optical image of sample 2 with Ip= 4A, Ton= 100µs and TP= 300 MPa, under 10 X magnification.

4.14.2 Effect of pulse on time

Fig.41, 42 and 43 shows optical microscopy images of the EDC coating for samples 3, 5 and 6. The effect of Ton during TiC-Cu coating on steel substrate was studied at Ton of 100 µs, 200 µs and 300 µs by keeping Ip as 5A and tool compaction pressure as 300 MPa. It is observed that thickness of deposited coating is maximum at Ton of 200 µs, since more sparks are generated and more material is deposited than at 100 µs. When Ton is further increased to 300 µs, there may be some undesirable heat loss due to the larger diameter of pulse, which cannot contribute to material removal from electrode and hence deposited a relatively thin layer of coating.

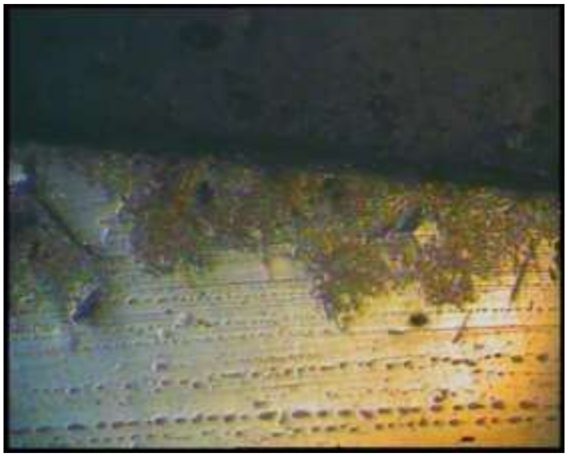

Fig.41: Optical image of sample 3 with Ip= 5A, Ton= 100µs and TP= 300 MPa, under 10 X magnification.

Fig.42: Optical image of sample 5 with Ip= 5A, Ton= 200µs and TP= 300 MPa, under 10 X magnification.

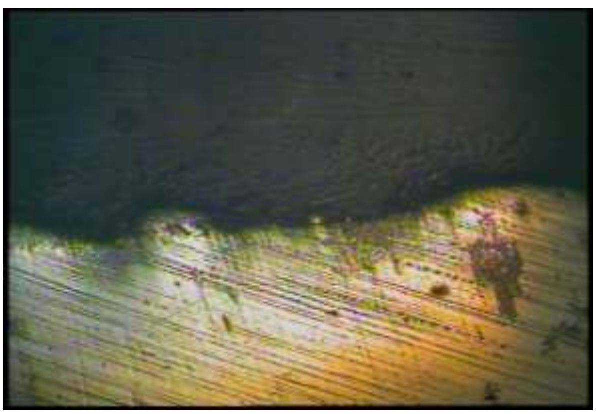

Fig.43: Optical image of sample 6 with Ip= 5A, Ton= 300µs and TP= 300 MPa, under 10 X magnification

Chapter 5

Conclusions:

Present study of Electrical Discharge Coating by ceramic-metal composite on metal substrate using Powder Compact Electrodes were conducted in two phases. From the first phase of Electro Discharge Coating process, the following conclusions can be made.

1. Through Electro Discharge Coating process WC-Cu composite layer has been deposited successfully over Al work piece surface.
2. Peak current (Ip) and pulse on time (Ton), during electro discharge process have most significant effect on the mean value of deposition rate and tool wear rate, but compaction pressure during tool electrode preparation has less effect on the mean value of deposition rate and tool wear rate.
3. Primary influencing factor for average micro hardness is tool compaction pressure followed by peak current and pulse on time.
4. With an increase of tool compaction pressure, the mean value of deposition rate and tool wear rate are reduced but the average micro hardness is increased.
5. With an increase of peak current (Ip) it has been observed that mean deposition rate, mean tool wear rate and average micro hardness is increased.
6. When pulse on time (Ton) increases from 100 µS to 200 µS both deposition rate and tool wear rate is increasing. But when Ton increases from 200 µS to 300 µS deposition rate and tool wear rate decreases. But average micro hardness is increased with the increase of pulse on time.
7. It is observed that the quality of the coating is becoming poor at high values of Ip and Ton.

During the second phase of the experiment AISI 1020 mild steel substrate is successfully coated with TiC-Cu. From this phase of experiments following conclusions can be made.

1. With the help of P/M tool electrode made of TiC and Cu, a composite layer of TiC-Cu has been successfully coated on AISI 1020 mild steel substrate through Electro Discharge Coating process.
2. It has been found that with the increase in peak current, the deposition rate decreases when pulse on time and tool compaction pressure kept constant.
3. When the pulse on time (Ton) increases from 100 µS to 200 µS deposition rate is increased. But when Ton increases from 200 µS to 300 µS, deposition rate reduced.
4. The average value of micro hardness is increased, when peak current and pulse on time is increased by keeping other parameters constant.
5. With an increase in peak current, it has been observed that the average value of surface roughness is increased, by keeping pulse on time and tool compaction pressure constant. Again, with increase in pulse on time, average surface roughness is increased when other parameters are constant.

Scope for Future Work:

The method of EDC will have a great scope for future works, because various materials can be used to prepare tool electrodes and different workpiece surface can be coated.

Further works can be carried out to study the frictional and wear behaviour of coating obtained.

Electrode prepared at different sintering condition can be use to create ceramic metal coating, for different characteristics of the coating.

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